

# **Quantifying Contact Rates and Space Use in the Eurasian Badger (*Meles meles*): Implications for the Transmission of Bovine Tuberculosis**

SUBMITTED BY NICOLA LOUISE REED (married name WEBER) TO  
THE UNIVERSITY OF EXETER  
AS A THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY  
IN BIOLOGICAL SCIENCES; SEPTEMBER 2011

This thesis is available for Library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified, and that no material has previously been submitted and approved for the award of a degree by this, or any other university.

N Reed.

.....

“The Mole had long wanted to make the acquaintance of the Badger. He seemed, by all accounts, to be such an important personage and, though rarely visible, to make his unseen influence felt by everybody about the place”

- Kenneth Grahame, *The Wind in the Willows*



# ABSTRACT

This thesis examines the space use, movement and contact rate patterns of a high- density, group-living, Eurasian badger (*Meles meles*) population in the UK naturally infected with bovine tuberculosis (bTB). Recently developed proximity logging devices were deployed on a representative sample of 51 badgers from eight different social groups to track their movements using radio-telemetry and to quantify their within- and between-group contact rates. Whilst interactions within social groups accounted for more than 90% of contacts, the entire study population was ultimately connected through interactions among individuals from neighbouring groups. Both within and between-group contacts, and also the use of denning sites, were heavily influenced by seasonal and demographic factors, which appear to be motivated to a large extent by reproductive behaviours. Nevertheless, by using social network analysis I found that badgers that tested positive for bTB were found to interact with fewer of their group members and for a shorter amount of time. Specifically these test-positive individuals were found to associate with test-negative group members significantly less than would be expected by chance. Those animals testing positive for bTB were also found to use outlying setts significantly more frequently than those that tested negative. The within and between-group contact rates of individuals were found to correlate with their sett use patterns. Those animals that spent less time interacting with group members and those that spent more time interacting with members of foreign social groups, were found to spend a greater proportion of their time at outlier setts. The findings in this thesis suggest a link between wider roaming behaviour and the disease status of an individual. This adds support to the argument that the social disruption of badger populations, for example through culling, may promote rather than alleviate the spread of bTB as a result of increased movement and contacts between groups. State-of-the-art technology has enabled me to demonstrate the strong influence that badger social organisation may have on the transmission of an economically significant infectious disease. My findings suggest that disease control measures might be enhanced by taking into account seasonal and individual-level variation in ranging behaviour and use of outlier setts, for example, by identifying and targeting functional groups of individuals, specific areas, or times of the year that contribute disproportionately to disease spread.

**KEYWORDS:** Eurasian badger, bovine tuberculosis, proximity loggers, contact rates, sett use patterns, social network analysis, individual-level heterogeneity.

## ACKNOWLEDGEMENTS

Firstly, a thank you to my supervisors Steve Carter, Stuart Bearhop and Sasha Dall for your time and help throughout this project, and for supporting my decisions when perhaps they didn't seem to be the best. In addition, Robbie McDonald and Dez Delahay were involved throughout, and read and commented on a large chunk of this thesis. The Department of the Environment, Food and Rural Affairs funded this work and I am grateful to them for the opportunity.

I would not have completed this project without the input of numerous people, and I am very grateful for all the help that has been given to me. I need to start by saying thanks to the Woodchester Park field team, Paul Spyvee, Sarah Boxall and Jess Mayo, for being so helpful with the fieldwork and badger capturing, even putting in extra trap-ups to get all of the collars out and retrieved, and for making me feel like part of the team. I want to thank everybody at Woodchester Park for being friendly and helpful, including Gavin Wilson, Alex Tomlinson and Kate Palphramand who have all contributed data to my thesis. I based some of my ideas on work done by Emily Goodman in her PhD thesis, sadly she passed away last year. I also need to thank Darren Croft and Joah Madden for willingly helping me with last minute social network panics, and to Tore Opsahl for answering my emails so quickly. I am also grateful to Julian Drewe and Nick Royle for helpful discussions. A big thank you to Xav Harrison for 'R Wizardery'; 'Contactweld' and 'Matrix Builder' (Appendices A&B) shaved weeks off my data filtering time. Finally, thank you very much to Tim Roper and Andy Young for taking the time to examine this thesis and for very helpful comments for the future manuscripts.

Love and thanks to my family, to Sam's family, and to my friends for all of the badger-related Christmas and birthday presents – but most importantly for their support and encouragement. Thanks also to Helen Bonsor for the lovely badger illustrations in this thesis. And to Sam for his interest and ideas on my project, for help with fieldwork and the write-up, for making me happy, and for putting life on hold for the past few months - adventure time starts now.

I dedicate this thesis to my family and husband.

# TABLE OF CONTENTS

<b>Abstract</b>		<b>3</b>
	Acknowledgements	4
	Table of Contents	5
	List of Tables	7
	List of Figures	9
	Author's Declaration	10
<b>Chapter 1.</b>	<b>General Introduction</b>	<b>12</b>
	1.1 The role of host ecology and behaviour in the spread of infectious disease	12
	1.2 Bovine tuberculosis and badgers	12
	1.3 Influence of heterogeneity in behavioural patterns on disease transmission	23
	1.4 Quantifying contact rates	25
	1.5 Aims and structure of the thesis	27
<b>Chapter 2.</b>	<b>Performance of proximity loggers in recording intra- and inter-species interactions: a laboratory and field-based validation study</b>	<b>30</b>
	2.1 Abstract	30
	2.2 Introduction	31
	2.3 Materials and Methods	33
	2.4 Results	39
	2.5 Discussion	46
<b>Chapter 3.</b>	<b>Sett use patterns of the Eurasian badger (<i>Meles meles</i>) correlate with bovine tuberculosis disease status</b>	<b>52</b>
	3.1 Abstract	52
	3.2 Introduction	53
	3.3 Materials and Methods	56
	3.4 Results	59
	3.5 Discussion	63
<b>Chapter 4.</b>	<b>Social life of the Eurasian badger (<i>Meles meles</i>): Proximity loggers provide new insights into contact patterns within and among social groups</b>	<b>68</b>
	4.1 Abstract	68
	4.2 Introduction	69
	4.3 Materials and Methods	71
	4.4 Results	77
	4.5 Discussion	89
<b>Chapter 5.</b>	<b>Contact patterns of the Eurasian badger (<i>Meles meles</i>) vary according to bovine tuberculosis disease status</b>	<b>96</b>
	5.1 Abstract	96
	5.2 Introduction	97
	5.3 Materials and Methods	100

	5.4 Results	105
	5.5 Discussion	113
<b>Chapter 6.</b>	<b>A quantitative comparison of methods used to study space use, movement and contact patterns in free-ranging animals using the Eurasian badger (<i>Meles meles</i>) as a test case</b>	<b>120</b>
	6.1 Abstract	120
	6.2 Introduction	121
	6.3 Materials and Methods	125
	6.4 Results	131
	6.5 Discussion	136
<b>Chapter 7</b>	<b>General Discussion</b>	<b>145</b>
	7.1 Overview	145
	7.2 Badger social organisation	149
	7.3 Disease transmission	151
	7.4 Other potentially important factors	152
	7.5 Management strategies	154
	7.6 Conclusion	158
<b>References</b>		<b>160</b>
<b>Appendices</b>		<b>178</b>
	Appendix A	179
	Appendix B	186
	Appendix C	195
	Appendix D	196
	Appendix E	197
	Appendix F	198

## LIST OF TABLES

<b>Table 2.1</b>	Changes in the detection distances of proximity loggers over time in the field	40
<b>Table 2.2</b>	Comparison of observed contacts with data recorded by proximity loggers	43
<b>Table 3.1</b>	Factors determining the proportion of time spent by badgers at the main vs. outlier setts	60
<b>Table 3.2</b>	Repeatability in individual badgers of the proportion of time spent at the main vs. outlier setts across seasons	61
<b>Table 4.1</b>	Numbers of collars deployed and total number of individuals present of different demographic classes across social groups during the study period 2009/10.	72
<b>Table 4.2</b>	Factors determining within and between-group contact durations of Eurasian badgers	79
<b>Table 4.3</b>	Test for assortative interactions between demographic classes of badgers across seasons	83
<b>Table 4.4</b>	Within-group degree centrality measures for different badger demographic groups	84
<b>Table 4.5</b>	Within-group closeness centrality measures for different badger demographic groups	85
<b>Table 4.6</b>	Between-group degree centrality measures for different badger demographic groups	87
<b>Table 4.7</b>	Between-group closeness centrality measures for different badger demographic groups	88
<b>Table 4.8</b>	Within and between-group flow-betweenness measures for different badger demographic groups	89
<b>Table 5.1</b>	Numbers of collars deployed and total number of individuals present of different demographic classes across social groups during the study period 2009/10.	101
<b>Table 5.2</b>	Tests for assortative interactions between bTB test-positive and negative badgers across seasons	109
<b>Table 5.3</b>	Degree centrality measures of bTB test-positive and negative	110

badgers across seasons

<b>Table 5.4</b>	Closeness centrality measures of bTB test-positive and negative badgers across seasons	111
<b>Table 5.5</b>	Flow-betweenness scores for bTB test-positive and negative badgers across seasons	112
<b>Table 6.1</b>	Methods for the study of movement and/or contact patterns in free-ranging animals	122
<b>Table 6.2</b>	Movement classifications assigned using capture-mark-recapture data	136
<b>Table A.C.1</b>	Demographic and geographical information for study groups in 2009 and 2010	195
<b>Table A.E.1</b>	The numbers of collars deployed on different demographic classes across social groups	197



## LIST OF FIGURES

<b>Figure 1.1.</b>	Conceptual framework for the transmission of bTB between badgers	15
<b>Figure 2.1.</b>	Photographs of proximity loggers attached to study animals	34
<b>Figure 2.2.</b>	Graphs showing the correlations between values recorded by interacting proximity loggers	42
<b>Figure 3.1</b>	The proportion of time spent at the main sett across seasons in relation to bTB test outcome	62
<b>Figure 3.2</b>	The proportion of time spent at the main sett in relation to sex, age and season	63
<b>Figure 4.1</b>	Average daily contact durations for badgers with other collared individuals within the same social group	78
<b>Figure 4.2</b>	Average between-group contact durations of study badgers during the different seasons	80
<b>Figure 4.3</b>	Contact networks and social group territories of a high-density badger population	82
<b>Figure 5.1</b>	Contact patterns and social group territories of a high-density badger population	106
<b>Figure 6.1</b>	Connectivity of badger social groups at Woodchester Park calculated using four different field methods	131
<b>Figure 6.2</b>	Connectivity of badger social groups at Woodchester Park in relation to successful between-group matings	132
<b>Figure 6.3</b>	Average connectivity of individual badgers at Woodchester Park as determined by four different field methods	133
<b>Figure 6.4</b>	Weighted diurnal networks for individuals determined using radio-telemetry and proximity loggers	134
<b>Figure 6.5</b>	Baitmarking map showing the configuration of badger territories at Woodchester Park in March 2009	135
<b>Figure A.D.1</b>	Baitmarking maps for 2009 and 2010	196
<b>Figure A.F.1</b>	Length of proximity logger deployment	198

## **AUTHOR'S DECLARATION**

The trapping records for all badgers and the data for the baitmarking maps were collected and complied by Food and Environment Research Agency (FERA) staff. Bait deployment, badger trapping, sampling and release were carried out by FERA staff, assisted by myself over the course of my study. Chapter 2 was carried out in collaboration with J. Drewe from the Royal Veterinary College who provided and analysed the entire cattle collar data presented and co-wrote the manuscript. My supervisors and others credited in the acknowledgements commented on earlier drafts of this work and/or provided unpublished data that was used in various chapters (indicated in the text). With these exceptions, I declare that the work contained in this thesis is my own and has not been submitted for any other degree or award. Trapping, anaesthesia and biological sampling of badgers were carried out under licence from the UK Home Office (licence number PPL60/3609) according to the Animals (Scientific Procedures) Act 1986. All procedures were approved by the FERA Ethical Review Panel.

Nicola Reed